

Effects of Stunning and Decapitation on Broiler Activity During Bleeding, Blood Loss, Carcass, and Breast Meat Quality

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ABSTRACT Four experiments were conducted to determine the effects of electrical stunning and decapitation on bird activity as well as carcass and meat quality. In Experiment 1, broilers were subjected to one of four stunning and killing methods: no stun and neck cut, stun and neck cut, no stun and decapitation, and stun and decapitation. Birds were scored for severity of physical activity on a scale of 1 to 4 with 1 being no activity and 4 being severe wing flapping and muscular contractions. Carcasses were also scored for red wing tips and broken bones. In Experiments 2 to 4, all birds were stunned prior to neck cut or decapitation. Carcasses were scored as described in Experiment 1 as well as measurements of blood loss, feather removal, and breast meat pH, color, cook loss, and tenderness. Based on carcass activity in

Experiment 1, decapitation following stunning was similar to a conventional stun and unilateral neck cut, except there was almost no late activity (after 60 s) observed in the decapitated birds. Decapitation following stunning did not result in any consistent carcass quality defects compared to conventional killing in the four experiments. No differences were found in 24-h lightness values, yellowness, cook yield, tenderness, and ultimate pH between conventionally killed and decapitated birds. Blood loss and breast meat redness were inconsistent. These results indicate that high frequency stunning and decapitation may be an acceptable alternative to conventional slaughter based on carcass and meat quality and by ensuring an irreversible loss of consciousness.

(*Key words:* carcass quality, decapitation, electrical stunning, meat quality)

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INTRODUCTION

Electrical stunning systems for poultry were initially developed to immobilize the bird long enough to allow physical manipulation of the bird for alignment in automated neck cutting equipment (killer) and to reduce carcass damage due to unconscious physical activity such as wing flapping and violent muscular contractions during bleeding. Commercial processing plants presently slaughter up to 140 to 180 birds a minute. Occasionally, due to a lack of bird uniformity, or poorly adjusted and maintained equipment, birds may miss one or both of the automated stunning and killing equipment, necessitating manual back-up. Consistency in making a proper unilateral neck cut, one that severs the carotid artery and the jugular vein, is necessary to allow rapid blood loss sufficient to kill the bird prior to entering the scalding and requires continual monitoring and equipment adjustment.

In the early 1980s, it was observed that as many as 30% of birds slaughtered in Europe were understunned

(Heath, 1984). Research was undertaken that led to the European Union recommendations for high-current stunning sufficient to cause instantaneous and irreversible unconsciousness in order to ensure a humane slaughter (van Hoof, 1992). These high-current, stun-to-kill methods have been associated with increased carcass and meat quality defects. According to Gregory and Wilkins (1989) high current stunning increases the incidence of red wing tips, broken bones, dislocations, hemorrhaging of deep breast muscle, and blood-engorged wing veins. Due to the importance of humane slaughter and meat quality issues, slaughter technology (live bird handling, stunning, killing, and bleeding) has received considerable research interest over the past 15 yr. Several authors have published reviews on the subject (Bilgili, 1999; Fletcher, 1999, 2000).

Effective electrical stunning is produced when a sufficient electrical current is passed through the central nervous system (CNS) of birds for a given time (Bilgili, 1992). According to Heath et al. (1994) more than 92% of all poultry plants in the US subject poultry to electrical stunning, and 66% of these plants use low voltage. Recent

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Abbreviation Key: a* = redness; b* = yellowness; L* = lightness; NY = New York.

advances in electrical stunning have focused on extending stunning times and lowering stunning voltage, with the use of high frequency (500 Hz) pulsed direct current (Bilgili, 1999). Humane slaughter may be obtained by an electrocution (stun-to-kill), as it reduces the risk of birds regaining consciousness from an insufficient stun, a lengthy stun-to-cut interval, or a improper neck cut (Kettewell and Hallworth, 1990). Kettewell and Hallworth (1990) also reported, a high-voltage stun using 105 to 110 mA per bird would achieve 90% heart fibrillation and lower the risk of birds regaining consciousness during slaughter. According to Gregory and Wotton (1990), the purpose of high-current stunning is to induce an epileptic waveform on electroencephalogram in the chicken brain activity. It is theorized that birds exhibiting such brain activity are insensible to pain and are unconscious, as there is no pain reported by humans who have experienced a grand mal or epileptic seizure.

Li et al. (1993) reviewed the various methods of post-mortem electrical stimulation (ES) used to accelerate rigor development in poultry carcasses. Electrical stimulation was found to hasten the development of rigor as measured by a rapid decrease in pH in thigh muscles of turkeys and to significantly reduce breast muscle shear values (Maki and Froning, 1987). Electrical stimulation can be utilized at a low (< 200 mA) or high (350–500 mA) amperage but is more effective with the high-amperage systems (Sams, 1999a,b). Electrical current when applied to the live bird (stunning) before death delays rigor, whereas electrical current applied seconds later to the dead or dying bird (electrical stimulation) accelerates rigor development (Fletcher, 1999).

It has been suggested that high-frequency (500 Hz) currents affect the CNS more than the muscular system compared to low frequency (50 to 60 Hz), which may have more affect on the muscular system. This observation was made by comparing the results of high- and low-frequency currents on stunning (Craig and Fletcher, 1997) and the lack of rigor acceleration when using high-frequency ES (Fletcher, 1998, unpublished data). Killing birds via decapitation is considered an acceptable means of killing (American Veterinary Medical Association, 1993). Although decapitation may be acceptable from a welfare standpoint, the massive involuntary wing flapping and muscular activity following decapitation results in unacceptable carcass damage as well as a poor aesthetic image. Based on the observations of high-frequency stunning affecting the CNS, it might be possible to kill birds using decapitation following a high-frequency stun without the massive muscular contraction. The objective of this study was to determine if decapitation following commercial high-frequency stunning would affect carcass muscular activity during bleeding and ultimate carcass and meat quality.

MATERIALS AND METHODS

Experiment 1

In each of two trials, 80 broilers were obtained from the live holding area of a commercial processing plant, transported to the university pilot processing facility, and processed immediately (within 1 h). In each of the trials, birds were weighed live and subjected to one of four stunning and killing treatments: no stun and unilateral neck cut (modified Kosher kill), stun followed by unilateral neck cut (conventional kill), no stun followed by decapitation (no stun:decap), and stun followed by decapitation (stun:decap). Stunning was conducted at 14 V, pulsed direct current at approximately 500 Hz for 18 s, followed by 14 V, 60 Hz AC for 9 s by a commercial stunner.² Killing was done by hand-cutting the carotid artery and jugular vein on one side of the neck (unilateral cut). During bleeding, the birds were subjectively scored for severity of early muscular activity (0 to 10 s postkill), intermediate activity (10 to 60 s postkill), and late activity (greater than 60 s postkill). Reactions were scored on a scale of 1 to 4 (1 = none to mild muscle quivering; 2 = mild wing flapping; 3 = moderate spasmodic body movement and full wing flapping; 4 = violent wing flapping and full-body movement capable of damaging the carcass). After 120 s, the birds were scalded³ at 54 C for 120 s and picked using a commercial in-line picker⁴ for 30 s. Heads were removed from the carcasses not decapitated at the same anatomical location as the conventional neck cutting or killing by decapitation, and New York (NY) dressed carcasses were weighed and chilled in a static ice and water mixture for 2 h. Carcasses were randomized and subjectively scored blind (scorer had no way to identify treatments) for occurrence and severity of the following carcass defects: red wing tips, red tails, and number of broken bones (clavicles and wing bones). Carcasses were scored on a scale of 0 to 2 (0 = no defects; 1 = moderate redness or one broken bone; 2 = severe redness or two or more broken bones).

Experiment 2

In each of two trials, 100 broilers were obtained and processed as described in Experiment 1 with the following exceptions: all birds were weighed, stunned, and divided equally among two killing methods using a unilateral neck cut (conventional kill) or decapitation. Following bleeding, approximately 120 s postkill, heads were removed from the conventionally slaughtered carcasses prior to weighing. Blood loss (including head) was estimated by the difference between live weight and headless weight after bleeding divided by live weight. Following scalding and picking, the NY-dressed carcasses were chilled as previously described. Carcasses were randomized and subjectively scored for occurrence and severity of red wing tips, red tails, and number of feathers where 0 = no defects or no feathers, 1 = moderate redness or less than three feathers, and 2 = severe redness or more than three feathers.

²Simmons model SF-7001, Simmons Engineering Co., Dallas, GA.

³Cantrell Model SS300CF, Cantrell Machine Co., Inc., Gainesville, GA.

⁴Cantrell Model CPF-60, Cantrell Machine Co., Inc., Gainesville, GA.

Experiment 3

In each of two trials, 100 broilers were obtained and processed as described in Experiment 2 with the following exceptions: in each trial there were 50 male and 50 female birds, and the decapitated heads were kept with the carcasses. Blood loss was determined by the difference between live weight and weight after bleeding divided by live weight (not including the loss of the head as in Experiment 2).

Experiment 4

In each of four trials, 100 broilers were obtained and subjected to the same treatments described in Experiment 2 except that birds were not weighed and carcasses were bled for 120 s prior to scalding, picking, and chilling of the NY-dressed carcasses. Carcasses were scored for occurrence and severity of defects as described in Experiment 2, after which the carcasses were covered with ice that was allowed to drain and held for 24 h at 2 C. Breast fillets (pectoralis major) were removed from both sides of the carcass. The right side was used for pH determination using a modification of the iodoacetate method of Jeacocke (1977) as described by Qiao et al. (2001). The left side was used to measure color, cook yield, and Allo-Kramer shear value. Breast fillet color was measured in triplicate on the medial surface and averaged for each fillet. Color was measured using the CIELAB color values of lightness (L^*), redness (a^*), and yellowness (b^*) using a reflectance colorimeter⁵ as described by (Qiao et al., 2001). Breast fillets were cooked in steam at 98 C for 20 min. Cook yield was determined as follows: $((\text{cooked weight}/\text{initial weight}) \times 100)$. Shear values were determined using an Allo-Kramer shear cell on an Instron Universal Testing Machine⁶ according to the procedure described by Papinaho and Fletcher (1996).

Statistical Analyses

Data within each experiment were analyzed using the ANOVA option of the general linear models procedure of SAS software (SAS Institute, 1988). Main effects for treatment (stunning and killing treatments), trials, and treatment-by-trial interactions were tested using residual error. When the treatment by trial interaction was significant, that error term was used to test treatment main effects. Means were separated by Duncan's multiple-range test option of the general linear models procedure (SAS Institute, 1988) with the appropriate mean square error as described above.

RESULTS AND DISCUSSION

Experiment 1

Bird live weights, carcass yields, reaction scores, and carcass defect scores for Experiment 1 are presented in

Table 1. No differences were found among treatments in bird weights (1,715 g), NY-dressed weight (1,540 g), or NY-dressed yields (89.8%).

Reaction scores during bleeding differed significantly among the four treatments. Birds in the no-stun:decap treatment reacted immediately (early and intermediate) with violent wing flapping and body motion (3.3 and 3.9, respectively). This activity steadily diminished in severity during the late period and was almost completely ended by 90 s post-decapitation. These observations were expected and were consistent with birds that had been decapitated or subjected to cervical dislocation.

Birds in the no-stun and conventional kill treatment (modified Kosher killing) exhibited little response to the handling and neck cut (Early, 1.8) but began exhibiting strong muscular contractions and wing flapping approximately 30 s postkill that continued through intermediate (3.0) and late (2.6) scoring periods. Some minor wing and body quivering was noted as late as 90 s postcut. The activity response for this treatment was also expected based on experiences with unstunned modified Kosher killing.

Birds stunned and killed with a unilateral neck cut (conventional killing) produced almost no initial reaction (early, 1.2), mild wing flapping and muscular contraction in the intermediate (2.0) and late (1.9) stages of bleeding, and some minor movement and quivering at 90 s. These activity observations are also consistent with those of birds killed in commercial plants.

The reaction of birds which were decapitated following stunning were almost identical in activity as the conventionally slaughtered bird in the early (1.0) and intermediate (1.6) periods. However, compared to the conventional kill there was almost no activity after 60 s (late, 1.5). This result was attributed to decapitation separating the brain from the carcass and killing the bird quicker without the lag time between neck cutting and the time required for blood loss to result in oxygen depletion to the brain as occurs during conventional slaughter. This supported the results for the unstunned and stunned conventionally killed birds still exhibiting some minor physical reactions at 90 s, whereas the decapitated birds showed almost no reactions by 90 s post-decapitation.

Reaction scores were higher for both of the no-stun treatments in all of the activity areas throughout bleeding than for the two stunning treatments. The highest scores were produced by the no-stun and decapitation treatment with 3.3, 3.9, and 2.4, respectively, for the early, intermediate, and late scoring intervals. The lowest reaction scores for early, intermediate, and late activities were from the stun and decapitation treatment with 1.0, 1.6, and 1.5, respectively.

No differences were found in the occurrence of red wing tips or number of broken bones among treatments. There was a significantly higher number of red tails in the conventional stun and kill treatment than in the other treatments. The carcasses were scored for redness and broken bones because of comments from processors who stated that decapitation (usually following a missed stun

⁵Minolta Chroma Meter CR-300, Minolta Corp., Ramsey, NJ.

⁶Instron Model 1122, Series 5500, Instron Corp., Canton, MA.

TABLE 1. Means and standard errors of the means for live weight, New York (NY) dressed weight, NY-dressed yield, early, intermediate, or late reaction severity, and occurrence of red wing tips, red tails, and broken bones from birds subjected to a conventional unilateral neck cut or decapitation without or following stunning in Experiment 1 (n = 40 observations per mean)

Variable	No stun		Stun		P
	Neck	Decapitation	Neck	Decapitation	
Live weight (g)	1,689 ± 45	1,722 ± 50	1,711 ± 32	1,740 ± 360	0.8510
NY-dressed weight (g)	1,516 ± 41	1,543 ± 45	1,538 ± 29	1,565 ± 33	0.8390
NY-dressed yield (%)	89.8 ± 0.14	89.7 ± 0.2	89.9 ± 0.2	89.9 ± 0.2	0.7100
Early ^{1,2}	1.8 ^b ± 0.31	3.3 ^a ± 0.32	1.2 ^c ± 0.05	1.0 ^c ± 0.13	0.0001
Intermediate ^{1,2}	3.0 ^b ± 0.19	3.9 ^a ± 0.06	2.0 ^c ± 0.10	1.6 ^c ± 0.13	0.0001
Late ^{1,2}	2.6 ^a ± 0.13	2.4 ^a ± 0.19	1.9 ^b ± 0.08	1.5 ^c ± 0.10	0.0001
Red wing tips ³	1.7 ± 0.11	1.7 ± 0.15	1.6 ± 0.10	1.5 ± 0.11	0.6656
Red tails ³	1.5 ^b ± 0.10	1.5 ^b ± 0.12	1.8 ^a ± 0.13	1.5 ^b ± 0.09	0.0402
Broken bones ³	1.1 ± 0.05	1.0 ± 0.03	1.1 ± 0.04	1.1 ± 0.05	0.6028

^{a-c}Means within a row followed by different superscript letters differ significantly ($P < 0.05$).

¹Reaction times; early = 0 to 10 s, intermediate = 10 to 60 s, Late = >60 s.

²Reaction scores (1 to 4) where 1 = none to mild muscle quivering, 2 = mild wing flapping, 3 = moderate spasmodic body movement and full wing flapping, and 4 = violent wing flapping and full-body movement capable of damaging the carcass.

³Carcass defect scores where 0 = no defects, 1 = moderate redness, and 2 = severe redness.

or kill) often resulted in poor bleeding, red discoloration, poor picking, and broken wings (personal communications with numerous processing plant supervisors). Based on the reactions noted for the no stun and decapitation treatment birds, these observations would be consistent with bird activity but were not reflected in the actual scores. Because of the clear difference in reactions between the stunned and not stunned treatments, all subsequent experiments were conducted following high-frequency stunning to focus on the comparison of conventional killing to decapitation following stunning.

Experiment 2

Live bird weights, weights after bleeding, blood and head loss percentages, and carcass defect scores for Experiment 2 are presented in Table 2. No differences were found in live or weights after bleeding among treatments.

Blood and head loss percentages for the conventional treatment were significantly higher than for the decapitated treatments, 5.6 and 5.4%, respectively. Assuming that the head weights would be randomly distributed, it is assumed that the difference in combined loss was due

primarily to differences in blood loss. There were no differences in the occurrences of red wing tips, red tails, or number of feathers observed among the treatments.

Based on previous research conducted with electrical stunning (Schutt-Abraham et al., 1983; Papinaho and Fletcher, 1995), these results are expected based on the strong heartbeat of the conventionally killed birds, facilitating a faster bleeding rate but with no effect on ultimate blood loss or carcass appearance when compared to birds killed with high-current stunning designed to cause heart fibrillation. However, estimating blood loss by weight difference in which the head weight was included might have been a confounding factor. Therefore, a method of keeping the detached head with the carcass was used in the subsequent experiment to focus strictly on the treatment effects on blood loss.

Experiment 3

Blood loss percentages for males and females from conventional and decapitated slaughtered treatments are presented in Table 3. There was a significant treatment-by-gender interaction, and so the treatment effects were

TABLE 2. Means and standard errors of the means for live weight, bled weight after removal of the head, blood loss percentage, and occurrence of red wing tips, red tails, and feathers from birds subjected to a conventional unilateral neck cut or decapitation following stunning in Experiment 2 (n = 100 observations per mean)

Variable	Treatment		P
	Conventional	Decapitation	
Live weight (g)	1,908 ± 26	1,923 ± 25	0.7260
Bled weight (g)	1,802 ± 25	1,820 ± 23	0.6376
Blood and head loss (%)	5.6 ± 0.1	5.4 ± 0.1	0.0311
Red wing tips ¹	0.91 ± 0.07	0.89 ± 0.08	0.5253
Red tails ¹	0.48 ± 0.07	0.51 ± 0.08	0.8408
Feathers ¹	0.18 ± 0.05	0.21 ± 0.06	0.5076

¹Carcass defect scores where 0 = no defects or no feathers. 1 = moderate redness or less than three feathers, and 2 = severe redness or more than three feathers.

TABLE 3. Means¹ and standard errors of the means for blood loss percentage for males and females subjected to conventional killing or decapitation in Experiment 3

Gender	Treatment		P
	Conventional	Decapitation	
Males	3.47 ± 0.13	3.49 ± 0.10	0.9032
Females	3.06 ± 0.15	3.22 ± 0.12	0.4170
P	0.0445	0.1082	

¹n = 50 observations per mean.

tested within gender. There were no significant treatment effects for the males, 3.47 and 3.49, or females, 3.06 and 3.22, for the conventional or decapitated birds, respectively. Males had a significantly greater blood loss in the conventional treatment, 3.47%, compared to females, 3.06%, respectively. These results do not agree with those in Experiment 2. Blood loss may not be consistent regarding method of slaughter, or estimating blood loss by weight difference may not be consistent, especially when the head is included in the calculations. Decapitation may not result in immediate heart fibrillation, thereby reducing the difference in blood loss rate when conventional killing is compared to electrocution.

Experiment 4

Carcass defects and 24 hour broiler breast meat pH, L*, a*, b*, cook yield, and Allo-Kramer shear values from Experiment 4 are presented in Table 4. There were no differences in the occurrence of red wing tips, red tails, and number of feathers between the slaughter treatments.

There were no significant differences between the breast meat pH from conventionally killed birds, 5.82, and the meat from decapitated birds, 5.83, indicating that killing treatment did not affect 24-h postmortem rigor development. There was no significant difference in breast meat color between killing treatments for L* or b*. However, the breast meats from the decapitated birds were significantly more red (2.6) than the breast meats from the conventionally killed birds (2.4). Although these values are numerically significant, they are of a magni-

tude that may not be visually significant. There were no killing treatment effects on breast meat cook yield or Allo-Kramer shear values.

It has been recommended that humane slaughter should be accomplished with instantaneous and irreversible loss of consciousness during stunning and bleeding (van Hoof, 1992). Although decapitation is not universally accepted as being humane, it is considered to be relatively rapid (loss of brain activity within 15 s; American Veterinary Medical Association, 1993) and it has to be considered irreversible. However, decapitation results in massive uncoordinated muscular activity immediately upon severing the spinal cord which has been associated with increased carcass damage and may often be viewed negatively from an aesthetic point of view. Because decapitation, or cutting the spinal cord, is related to severe reactions and the perception by processing plant personnel of increased carcass damage (not directly supported by our data), decapitation has not received much interest as a possible method for commercial slaughter. These results indicate that high-frequency stunning followed by immediate decapitation may be an acceptable method of slaughter based upon rapid death, suppression of muscular activity upon severing the spinal cord, and no apparent carcass quality or meat defects. Further research is necessary to determine if decapitation following stunning would be applicable under commercial conditions relative to line speeds, carcass spacing on the line (6-inch commercial standard versus 12-inch in this study), and the occurrence of defects that may be significant in the large numbers of processed birds associated with com-

TABLE 4. Mean and standard error of the mean for occurrence of red wing tips, red tails, feathers, breast meat pH, lightness (L*), redness (a*), yellowness (b*), cook yield, and Allo-Kramer shear from birds subjected to a conventional unilateral neck cut (Conventional) or decapitation following stunning in Experiment 4 (n = 200 observations per mean)

Variable	Treatment		P
	Conventional	Decapitation	
Red wing tips ¹	0.93 ± 0.05	0.94 ± 0.04	0.8423
Red tails ¹	0.80 ± 0.06	0.68 ± 0.05	0.1230
Feathers ¹	0.06 ± 0.02	0.05 ± 0.01	0.6386
Breast meat pH	5.82 ± 0.01	5.83 ± 0.01	0.5157
L*	49.8 ± 0.24	49.6 ± 0.23	0.6227
a*	2.4 ± 0.07	2.6 ± 0.07	0.0016
b*	6.3 ± 0.11	6.4 ± 0.12	0.5842
Cook yield (%)	73.18 ± 0.18	73.41 ± 0.21	0.4092
Allo-Kramer (kg/g)	5.06 ± 0.16	4.94 ± 0.15	0.5269

¹Carcass defect scores where 0 = no defects or no feathers, 1 = moderate redness or less than three feathers, and 2 = severe redness or more than three feathers.

mercial slaughter (hundreds of thousands per day as opposed to 200 to 400 per experimental trial).

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REFERENCES

- American Veterinary Medical Association. 1993. Report of the AVMA panel on euthanasia. *J. Am. Vet. Med. Assoc.* 202:229–249.
- Bilgili, S. F. 1992. Electrical stunning of broilers—basic concepts and carcass quality implications: A review. *J. Appl. Poult. Res.* 1:135–146.
- Bilgili, S. F. 1999. Recent advances in electrical stunning. *Poult. Sci.* 78:282–286.
- Craig, E. W., and D. L. Fletcher. 1997. A comparison of high current and low voltage electrical stunning systems on broiler breast rigor development and meat quality. *Poult. Sci.* 76:1178–1181.
- Fletcher, D. L. 1999. Slaughter technology. *Poult. Sci.* 78:277–281.
- Fletcher, D. L. 2000. Stunning of poultry. Proceedings of XXI World Poultry Congress, Montreal. WPSA, Montreal, Canada.
- Gregory, N. G., and L. J. Wilkins. 1989. Effect of stunning current on carcass quality defects in chickens. *Vet. Rec.* 124:530–532.
- Gregory, N. G., and S. B. Wotton. 1990. Effect of stunning on spontaneous physical activity and evoked activity in the brain. *Br. Poult. Sci.* 31:215–220.
- Heath, G. B. S. 1983. The slaughter of broiler chickens. *World's Poult. Sci. J.* 40:151–159.
- Heath, G. E., A. M. Thaler, and W. O. James. 1994. A survey of stunning methods currently used during slaughter of poultry in commercial poultry plants. *J. Appl. Poult. Res.* 3:297–302.
- Jeacocke, R. E. 1977. Continuous measurements of the pH of the beef muscle in intact beef carcasses. *J. Food Technol.* 12:375–386.
- Kettlewell, P. J., and R. N. Hallworth. 1990. Electrical stunning of chickens. *J. Agric. Eng. Res.* 47:139–151.
- Li, Y., T. J. Siebenmorgen, and C. L. Griffis. 1993. Electrical stimulation in poultry: A review and evaluation. *Poult. Sci.* 72:7–22.
- Maki, A., and G. W. Froning. 1987. Effect of post-mortem electrical stimulation on quality of turkey meat. *Poult. Sci.* 66:1155–1157.
- Papinaho, P. A., and D. L. Fletcher. 1995. Effects of electrical stunning duration on post-mortem rigor development and broiler breast meat tenderness. *J. Muscle Foods* 6:1–8.
- Papinaho, P. A., and D. L. Fletcher. 1996. The effects of stunning amperage and deboning time on early rigor development and breast meat quality of broilers. *Poult. Sci.* 75:672–676.
- Qiao, M., D. L. Fletcher, D. P. Smith, and J. K. Northcutt. 2001. The effect of broiler breast meat color on pH, moisture, water-holding capacity, and emulsification capacity. *Poult. Sci.* 80:676–680.
- Sams, A. 1999a. Meat quality during processing. *Poult. Sci.* 78:798–803.
- Sams, A. 1999b. Commercial implementation of postmortem electrical stimulation. *Poult. Sci.* 78:290–294.
- SAS Institute. 1988. SAS/STAT Guide for Personal Computers. Version 6.03 Edition. SAS Institute Inc., Cary, NC.
- Schutt-Abraham, I., H.-J. Wormuth, and J. Fessel. 1983. Electrical stunning of poultry in view of animal welfare and meat production. Pages 187–196 in *Stunning of Animals for Slaughter*. G. Eikelenboom, ed. Martinus Nijhoff, Boston, MA.
- van Hoof, J. B. M. 1992. Final remarks and recommendations. Page 69 in *Proceedings of the EC Workshop on Pre-Slaughter Handling and Stunning of Poultry*, Brussels.